

Diffractive Meson Production and the Quark-Pomeron Coupling

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Abstract

Diffractive meson production at HERA offers interesting possibilities to investigate diffractive processes and thus to learn something about the properties of the pomeron. The most successful phenomenological description of the pomeron so far assumes it to couple like a $C = +1$ isoscalar photon to single quarks. This coupling leads, however, to problems for exclusive diffractive reactions. We propose a new phenomenological pomeron vertex, which leads to very good fits to the known data, but avoids the problems of the old vertex.

1 Introduction

The start of HERA has opened very promising possibilities to investigate the nature of the pomeron [1]. For example the new data for F_2 seem to favour the BFKL–pomeron which is calculated within perturbative QCD, but the Donnachie–Landshoff pomeron is not ruled out definitely [2]. The latter, however, gives a perfect description of all aspects of diffractive hadronic reactions, which the BFKL–pomeron does not. In addition the BFKL–pomeron is problematic for theoretical reasons [3].

We do not want to investigate the relation between the pomeron and F_2 or the consequences of the different pictures for the structure functions. Instead we investigate a certain class of processes in some detail, namely diffractive meson production in lepton–nucleon and nucleon–nucleon scattering. We start from the Donnachie and Landshoff (DL) pomeron, and concentrate on the coupling of the pomeron to single quarks.

The diffractive J/Ψ production in nucleon–nucleon collisions was already suggested [4] as an attractive possibility to learn more about the pomeron’s coupling to single quarks in hadronic matter. The background from χ production has been calculated too [5].

We have tried to apply a similar program for diffractive events at HERA, but it turned out that the traditional DL–pomeron cannot describe them in an unambiguous way.

The failure of the classical pomeron description motivated us to investigate its coupling to quarks, suggesting a new effective vertex. This new vertex is used to calculate several cross sections for diffractive production of vector mesons, in lepton–nucleon as well as in nucleon–nucleon scattering. The results offer definite possibilities to distinguish between the traditional picture and the new one.

In addition we guarantee that well established results as total nucleon–nucleon cross sections and elastic proton–proton cross sections are described well by the modified coupling.

The last process we discuss is the exclusive ρ production in DIS. For this process the situation is rather unclear. The results for both vertices look qualitatively fine, but the normalization is somewhat off. This point needs further clarification. It is certainly related to the fact that here the quark masses are much smaller than $M_\rho/2$. The fraction of longitudinally polarised ρ mesons can be described in both pictures.

In summary the modified coupling allows to describe Φ production at HERA in a reasonable way and it predicts clear signals for J/Ψ production in nucleon–nucleon collisions. Therefore it would be of great interest to get experimental data for these processes.

2 Diffractive meson production at HERA

The production of $J^{PC} = 1^{--}$ mesons in diffractive events at HERA opens new possibilities to test the coupling of the pomeron to single quarks. Figure 1 shows the relevant Feynman graph, with the four momenta attributed to the involved particles. In the following we consider the production of $\Phi(1020)$ mesons. For J/Ψ the mechanism is the same, but the cross sections are smaller due to the larger mass and the smaller size of this meson.

The Φ meson is described as a non relativistic bound state of a $s\bar{s}$ pair, figure 2. There are

two contributions for the different directions of momentum flow, and since the pomeron has $C = +1$ the two amplitudes have to be subtracted. A formal derivation of this sign is given in [4]. Note that for two-photon fusion both amplitudes would have to be added coherently and the sum would vanish identically [6].

We use the normalization of [7, 4] and take the following expression for the q - \mathbb{P} - Φ vertex:

$$T_{\mu\alpha} = e_q \beta \sqrt{3} A \times \text{tr} \left\{ \not{\epsilon}_\Phi (\not{P} + M_\Phi) \left[\gamma_\mu \frac{-\not{P} + \frac{1}{2}\not{P} + m_s}{(\frac{1}{2}P - \not{P})^2 - m_s^2} \Gamma_\alpha - \Gamma_\alpha \frac{\not{P} - \frac{1}{2}\not{P} + m_s}{(-\frac{1}{2}P + \not{P})^2 - m_s^2} \gamma_\mu \right] \right\}. \quad (1)$$

The normalization constant A can be related to the e^+e^- decay width

$$3A^2 = 3 \frac{2\pi \Gamma_{ee} M_\Phi}{e_q^2 e^2}, \quad (2)$$

where the factor 3 counts the colours and e_q is the electric charge of the s -quark. The strength of the pomeron's coupling to a single quark is described by the "charge" β . γ_μ is the usual quark-photon vertex while Γ_α is the quark-pomeron vertex, which we want to investigate in more detail.

With these conventions the squared Feynman amplitude reads

$$|\mathcal{M}|^2 = \sum_{\varepsilon_\Phi} \left[\frac{1}{q^2} \left(\frac{s}{s_1} \right)^{\alpha \mathbb{P} - 1} F_N(\mathbb{P}^2) \right]^2 l^{\mu\nu} h^{\alpha\beta} T_{\mu\alpha} T_{\nu\beta}^*, \quad (3)$$

with the usual leptonic tensor

$$l^{\mu\nu} = \frac{1}{2} \text{tr} [(\not{l} + m_e) \gamma^\mu (\not{l}' + m_e) \gamma^\nu] \quad (4)$$

and the hadronic tensor

$$h^{\alpha\beta} = \frac{1}{2} \text{tr} [(\not{p} + m_N) \Gamma^\alpha (\not{p}' + m_N) \Gamma^\beta]. \quad (5)$$

The quantity s_1 , used to normalise s in the pomeron propagator, is defined by [8]

$$s_1 = (l' + P)^2. \quad (6)$$

The pomeron trajectory is taken to be linear [9, 10]

$$\alpha_{\mathbb{P}}(t_{\mathbb{P}}) = 1 + \varepsilon + \alpha' t_{\mathbb{P}}, \quad (7)$$

with the following parameters

$$\varepsilon = 0.08, \quad \alpha' = 0.25 \text{ GeV}^{-2}, \quad (8)$$

and the "charge" β has the value

$$\beta = 1.8 \text{ GeV}^{-1}. \quad (9)$$

The isoscalar form factor at the proton-pomeron vertex is written in the dipole approximation as

$$F_N(t) = \frac{4m_N^2 - 2.8t}{4m_N^2 - t} \left(1 - \frac{t}{0.7 \text{ GeV}^2}\right)^{-2}. \quad (10)$$

To evaluate the differential cross section we integrate over the appropriate phase space. This is done by using a Monte Carlo algorithm. All our results are calculated exactly in this sense without any approximation. For the DL-vertex, $\Gamma_\alpha = \gamma_\alpha$, the shape of the resulting differential cross section, shown in figure 3, has the expected form but the absolute values are in the region of several barns, which can not be true.

This problem can be traced back to the violation of gauge invariance. In QCD the pomeron is in principle described by the exchange of two gluons and we should take into account all six permutations of the coupling of two gluons and a photon to a quark-line. The single contributions would cancel, and the resulting cross sections would be of the order of several nb. Since we use the effective description of the pomeron, we do not take into account all graphs and the cancellation does not take place.

To resolve this problem and to keep the simple picture of the pomeron coupling to single quarks, one could introduce a form factor for the Φ -vertex. But a reasonable guess does not change the results dramatically.

We tried another possibility, namely a modification of the effective quark-pomeron coupling. With the four momenta k and $k' = k + \mathbf{P}$ for incoming and outgoing quark we introduce the new effective vertex, given by

$$\Gamma_\alpha = \frac{1}{2} \left(\gamma_\alpha + \frac{|k + k' \pm \mathbf{P}|}{2(|k^2| + |k'^2|)} (k + k')_\alpha \right), \quad |k + k' \pm \mathbf{P}| = \sqrt{(k + k' \pm \mathbf{P})^2}. \quad (11)$$

This definition implicitly makes use of the fact, that the pomeron couples to single constituent quarks in hadrons, corresponding to the well established quark counting rule. In this simple and very successful picture the constituent quarks carry a nonvanishing mass. E.g. for mesons $m_q = M/2$ and for the nucleon we have $m_q = m_N/3$. The two signs correspond to the coupling to quark and antiquark, respectively. It turns out that this choice of the coupling is unique, i.e. this is the only possibility to obtain sensible results for diffractive meson production. In most of the processes we studied small momentum transfers dominate, and equation (11) reduces to a much simpler expression.

E.g. for the two graphs in figure 2 the quark-pomeron vertices read

$$\Gamma_\alpha^{(1)} = \frac{1}{2} \left(\gamma_\alpha - \frac{M_\Phi}{M_\Phi^2 - q^2 - \mathbf{P}^2} q_\alpha \right) \quad \text{and} \quad \Gamma_\alpha^{(2)} = \frac{1}{2} \left(\gamma_\alpha + \frac{M_\Phi}{M_\Phi^2 - q^2 - \mathbf{P}^2} q_\alpha \right), \quad (12)$$

and for diffractive meson production only small values of $-q^2, -\mathbf{P}^2 \ll M_\Phi^2$ are involved, resulting in the following effective form

$$\Gamma_\alpha^{(1)} \simeq \frac{1}{2} \left(\gamma_\alpha - \frac{1}{M_\Phi} q_\alpha \right) \quad \text{and} \quad \Gamma_\alpha^{(2)} \simeq \frac{1}{2} \left(\gamma_\alpha + \frac{1}{M_\Phi} q_\alpha \right). \quad (13)$$

The hadronic tensor has to be modified analogously by substituting

$$\Gamma_\alpha \simeq \frac{1}{2} \left(\gamma_\alpha + \frac{1}{2m_N} (p + p')_\alpha \right). \quad (14)$$

This nucleon pomeron vertex is derived by interpreting the nucleon as consisting of three constituent quarks, each one carrying a third of the nucleon's momentum. Consistently the quark mass is taken to be a third of the nucleon's mass.

The corresponding changes for the hadronic tensor do not lead to pronounced effects, for unpolarised reactions. Nevertheless we take them into account to be able to analyse polarization effects in section 5.

Figure 4 shows the differential cross section obtained with the new coupling. Now the results look plausible, not only the shape but the absolute values too.

This first success encourages us to suggest (11) as an alternative for the pomeron–quark coupling. In the following we work out the consequences for several processes.

First we should have a look at the vertex in some detail. The Gordon identity relates the γ -coupling and the momentum dependent terms:

$$\bar{u}(k') \gamma_\alpha u(k) = \bar{u}(k') \left[\frac{1}{2m_N} (k + k')_\alpha + \frac{i}{2m_N} \sigma_{\alpha\alpha'} \mathbf{P}^{\alpha'} \right] u(k), \quad (15)$$

with the transferred momentum \mathbf{P} . The two expressions differ by a term containing the spin matrices $\sigma_{\alpha\alpha'}$, which could in principle generate spin dependent cross sections.

The first possibility we have is to fix the helicity of incoming and outgoing electron and proton and to sum over all polarizations of the produced Φ . The helicity operator, e.g. for the incoming electron, is given by

$$\Sigma_e = \frac{1}{2} (1 + \gamma_5 \not{s}), \quad s^\mu = (|\vec{l}|, E_l \hat{l}), \quad (16)$$

with energy E_l and the unit vector \hat{l} in the direction of \vec{l} [11].

Since $m_e/E_l \ll 1$ the spin flip of the electron is strongly suppressed. This effect stems solely from the vertex at the electronic current. Therefore we fix the helicity for the electron to remain unchanged after the scattering.

For a pure γ -coupling of the pomeron the flip of the proton's helicity is suppressed strongly too, as the solid curve of figure 6 shows. It represents the proportion of the differential cross sections for helicity flip and no flip within the traditional description (DL). The dashed-dotted curve shows the same quantity but calculated with the modified vertex (SK). Here the helicity flip is enhanced to about one percent of the cross section for unchanged helicity.

A second interesting possibility is to look at the Φ 's polarization in some detail. For transverse mesons $\sigma_{flip}/\sigma_{noflip}$ is about 0.7% for small momenta, raising to about 1.5% at $P_\Phi = 100$ GeV, while this quantity is nearly constant at 2% for a longitudinally polarised Φ , figure 6.

Since the differences are small, the experiments at HERA probably could not detect them. But there is another interesting quantity leading to a clear signal. In figure 7 we show

the fraction of longitudinally produced Φ 's in the scattering of longitudinally polarised electrons and protons. The solid curve for DL shows that nearly all mesons are produced in a longitudinal state in the traditional picture. For the new vertex only a fraction of about $30\% \pm 10\%$ is produced longitudinally. Measuring the Φ polarization, e.g. by analysing the angular correlations of its decay products, if feasible, would therefore be a very important experiment for pomeron phenomenology.

For J/Ψ production at HERA the first experimental data for the total cross section have just been published [12], the result is $\sigma_{tot} = 8.8 \pm 2.0 \pm 2.2$ nb. In figure 5 we show the differential cross section for diffractive production, calculated with the vertex (11). The results include an ad hoc factor $N = 0.1$ to take into account the small size of the J/Ψ meson. This factor corresponds to the effect of some unspecified pomeron form factor suppressing diffractive processes when the produced meson is smaller than the pomeron. Its value is chosen very small such that our result has to be understood as a lower bound. The resulting value for the integrated cross section is $\sigma_{diff} = 4.0 \pm 1.0$ nb. The error corresponds to the cut-off for higher meson momenta where the usual pomeron description is not applicable [10]. Bearing in mind the uncertainty parametrised by the factor N the order of magnitude of our result looks fine.

Finally we note an interesting property of the new vertex (11). The second term in parentheses invalidates the usual relationship between diffractive scattering and the behaviour of $F_2(x)$ for small x , depending on the adapted $i\eta$ -procedure [13]. This might open a loophole if the $F_2(x)$ -data were found to exclude definitely an asymptotic behaviour $x^{-\epsilon}$.

3 Nucleon-nucleon cross sections

The Γ -coupling introduced in the last section gives reasonable results for diffractive production of Φ mesons at HERA, but this is not the only possibility to test the new vertex, since there exists a lot of experimental data described by the DL-pomeron in outstanding agreement. Maybe the most important example is the total cross section for nucleon-nucleon scattering. In the traditional picture the total cross section is described by [14]

$$\sigma_{NN}^{tot} = A_{NN} s^{-0.56} + B s^\epsilon. \quad (17)$$

The first term describes ρ, ω, \dots -exchange and the coefficient A_{NN} is different for pp and $p\bar{p}$ scattering. The second term corresponding to pomeron exchange is the same for both cross sections and is related to the elastic cross section through the optical theorem:

$$\sigma_{NN}^{tot} \sim \Im \left(\mathcal{M}^{el} \Big|_{t=0} \right) = \Im \left((3\beta)^2 F_N^2(t) J_\alpha J^\alpha \left(\frac{s}{m_N^2} \right)^{\alpha \mathbb{P}^{-1}} \Big|_{\mathbb{P}=0} + \rho, \omega, \dots \right), \quad (18)$$

where J_α is the hadronic current. Since the amplitude is evaluated for vanishing pomeron four momentum, $\mathbb{P} = 0$, the Gordon identity (15) ensures that the new vertex reproduces the result (17). This calculation was used to fix the normalization factor $\frac{1}{2}$ for the new vertex.

Another touchstone for any parametrisation of the pomeron are the cross sections for elastic proton-proton scattering [14]. In figure 8 the results for the DL-pomeron and our modified form are compared for a cms energy $\sqrt{s} = 52.8 \text{ GeV}$ and in figure 9 the same quantity is plotted for $\sqrt{s} = 550 \text{ GeV}$. For small values of momentum transfer $|t|$ the two curves agree very well and the differences for larger $|t|$ are about one percent.

The good agreement for small values of $|t|$ can be traced back to the Gordon identity (15). For high energy and small momentum transfer the components of the pomeron's four momentum are small compared to the energy of the protons. (The picture of the pomeron is only applicable for $\omega_{\mathbb{P}} < 0.1 \cdot E_N$.) Therefore the coupling is dominated by the first term, involving the four momenta of incoming and outgoing proton:

$$2m_N \gamma_\alpha = (p + p')_\alpha + \sigma_{\alpha\alpha'} \mathbb{P}^{\alpha'} \approx (p + p')_\alpha . \quad (19)$$

In summary we conclude that both the total and elastic cross sections for nucleon-nucleon scattering are described equally well by both pomeron vertices.

4 Diffractive meson production in nucleon-nucleon collisions

Another process involving the pomeron is double diffractive production of J/Ψ mesons in nucleon-nucleon collisions. In this process the dominant contribution stems from pomeron-odderon fusion [4]. The relevant Feynman diagrams are shown in figure 10, and the reader should keep in mind that each diagram represents two contributions for the different directions of momentum flow at the $\mathbb{P}\text{-}\mathbb{O}\text{-}J/\Psi$ -vertex. Another point we want to emphasize is the relative minus sign for pp scattering, while the two graphs have to be added for $p\bar{p}$.

The odderon is essentially taken to be the $C = -1$ counterpart of the pomeron [15]. It's coupling to quarks is assumed to be the same as for the pomeron, namely γ_α in the traditional picture and Γ_α for the new coupling, respectively.

The odderon coupling strength is written as $c_0\beta$ instead of β , with $c_0 \approx 0.05$ [15]. For it's trajectory we assume a linear form

$$\alpha_{\mathbb{O}} = 1 + 0.1 \text{ GeV}^{-2} \cdot t_{\mathbb{O}} . \quad (20)$$

The effects of varying the parameters in (20) are small [4].

Again the resulting cross sections are multiplied by a factor N to take roughly into account the small size of the J/Ψ meson. For double diffractive processes this factor is taken to be $N = 0.01$.

In figure 11 we show the differential cross sections for J/Ψ production for $\sqrt{s} = 2 \text{ TeV}$, which corresponds to the energies of 1 TeV for each nucleon. The solid curves show the results for a pure γ -coupling lying in the region of nb. For $p\bar{p}$ scattering the cross section is about one order of magnitude smaller, since we get destructive interference between the two graphs of figure 10.

The signal for the odderon, namely the large ratio between the pp and $p\bar{p}$ cross section, stays the same for the new vertex, but the overall size is reduced strongly, making experiments difficult.

If c_0 were known (which it is not [16]) the measurement of the J/Ψ cross section would be a good probe to decide between the two pomeron models.

There is, however, another process for J/Ψ production which offers some possibilities to look at the pomeron's coupling. It is the indirect J/Ψ production via the pomeron-pomeron fusion into one of the χ mesons. There exist three of them distinguished by their spin and each of them can decay into a J/Ψ and a photon [5]. Since the pomeron couples in the same way to p and \bar{p} , the cross sections for diffractive χ production are the same for pp and $p\bar{p}$ scattering.

For pure γ -coupling the background of these processes can be neglected. The relevant cross sections multiplied by the branching ratios

$$\frac{\Gamma_{J/\Psi}}{\Gamma}(0^{++}) \approx 6.6 \cdot 10^{-3}, \quad \frac{\Gamma_{J/\Psi}}{\Gamma}(1^{++}) \approx 0.273, \quad \frac{\Gamma_{J/\Psi}}{\Gamma}(2^{++}) \approx 0.135 \quad (21)$$

are much smaller than 0.1 nb/GeV, cf. figure 12.

For the new vertex the situation is completely different, now this "background" is contributing more than $\text{IP-}\text{D}$ -fusion, figure 13.

The J/Ψ from χ decay into $J/\Psi + \gamma$ can easily be discriminated by detection of the photon. Since the cross section with the Γ -vertex is three orders of magnitude larger than the cross section calculated within the traditional picture it should be possible to distinguish between the two pictures, see figure 14.

One way or another, diffractive processes in nucleon-nucleon collisions give us a new tool to investigate the pomeron in some detail. Even if the direct J/Ψ production is not accessible to present experiments, the χ production could give interesting informations about the pomeron's coupling.

5 Exclusive ρ production in DIS

Another process where the concept of the pomeron has been used with success is the exclusive production of ρ mesons in DIS [17]. The relevant graph is similar to that for Φ production at HERA, but we consider the scattering of a virtual photon off a proton, figure 15. The cross section for exclusive ρ production have been measured by EMC for several values of $W^2 = (q+p)^2$, and $Q^2 = -q^2$, [18]. Since the results do not depend strongly on the value of W^2 , we take for definiteness $W^2 = 81 \text{ GeV}^2$.

The normalization of our cross section is given by the following expression

$$\begin{aligned} d\sigma^{(\lambda)} = & \frac{4\pi^2\alpha}{K} \frac{1}{4\pi m_p} (2\pi)^4 \delta^4(q+p-p'-P) (3\beta)^2 F_N^2(t) (\alpha' W^2)^{2\alpha} \text{IP}^{-2} \\ & \sum_{\varepsilon} \varepsilon^{\mu} \varepsilon^{\nu} h^{\alpha\beta} T_{\mu\alpha}^{(\lambda)} T_{\nu\beta}^{(\lambda)*} \frac{d^3 p' d^3 P}{(2\pi)^6 4E'_p E_{\rho}} \end{aligned} \quad (22)$$

with $\lambda = 0$ for longitudinally and $\lambda = \pm 1$ for transversely polarised ρ mesons. The normalization constant $3A^2$ can be calculated in analogy to (2). The flux factor K is chosen in the usual way $K = (W^2 - m_p^2)/2m_p$. As before the amplitude $T_{\mu\alpha}$ sums up coherently both directions of momentum flow. The normalization constant in the pomeron's propagator is fixed as $\alpha' = 0.25 \text{ GeV}^{-2}$ [9].

With this expression, keeping the "charge" β fixed for all values of Q^2 , we get the results shown in figure 16. The squares and the error bars mark approximately the range of the experimental data for several values of W^2 and muon energy for $Q^2 = 1, 2, 10 \text{ GeV}^2$, respectively [18].

The cross section calculated with the traditional γ -coupling (DL) contains an additional form factor

$$\frac{\mu_0^2}{\mu_0^2 - k^2}, \quad \mu_0 \approx 1.2 \text{ GeV}, \quad (23)$$

suppressing the coupling of the pomeron to the quark in the loop. This quark of momentum k , figure 15, is far off shell and (23) was introduced to get the correct Q^2 dependence of the cross section [17]. The quantity μ_0 is fixed by the relation of pomeron exchange and the proton's structure function $F_2(x)$ for small x .

With these ingredients the shape of the experimental data is reproduced very well, but the absolute values differ approximately by a factor of two. This is in contrast to the results quoted in [17], which are in good agreement with experiment. To make a comparison possible we give our normalization of the cross section (22).

The cross section calculated with the Γ -vertex (SK) is about two times larger than the experimental data. Bearing in mind that the applicability of our model is questionable due to the large p_T of the ρ and the smallness of the up and down quark masses this agreement is quite encouraging. The shape of the results is compatible with experiment, and we want to emphasize that this result is calculated without any additional form factor (23).

Another quantity measured by EMC is the fraction of longitudinally polarised ρ mesons defined by

$$\frac{\sigma_{long}}{\sigma_{tot}} = \frac{\sigma^{(\lambda=0)}}{\sum_{\lambda=0,\pm 1} \sigma^{(\lambda)}}, \quad (24)$$

The results for both couplings are shown in figure 17. With the traditional γ -coupling the polarization of the ρ -meson is described in good agreement.

With the new coupling the experimental data are described within error bars. This property depends crucially on the concrete definition of (11), respectively (12). This representation apparently shows a suppression of the momentum dependent term for higher momentum transfers, and this suppression is responsible for the resulting Q^2 -dependence of the polarization.

Finally we want to stress that the new vertex describes correctly diffractive nucleon-nucleon scattering, Φ production and ρ -production without any further assumption and that the combination in (11) is unique in doing so. This effective quark-pomeron coupling should guide QCD based investigations of the pomeron.

6 Summary

The investigation of the pomeron is currently of great interest. Attempts to derive its properties from QCD in a rigorous way are faced with enormous technical difficulties [3]. Therefore experiments feasible, e.g. at HERA, can only be sensibly compared with results from phenomenological models like the Donnachie–Landshoff pomeron. We proposed a modified pomeron model which reproduces all the successes of the DL–pomeron. Our result is unique, and avoids a number of problems arising due to the violation of gauge invariance. We have shown that diffractive meson production is very sensitive in discriminating between the two models. Additionally our vertex leads to spin–effects which, although small, might be observable at HERA. If the phenomenologically correct vertex structure were determined by such experiments this could guide the effort of deriving the pomeron from QCD.

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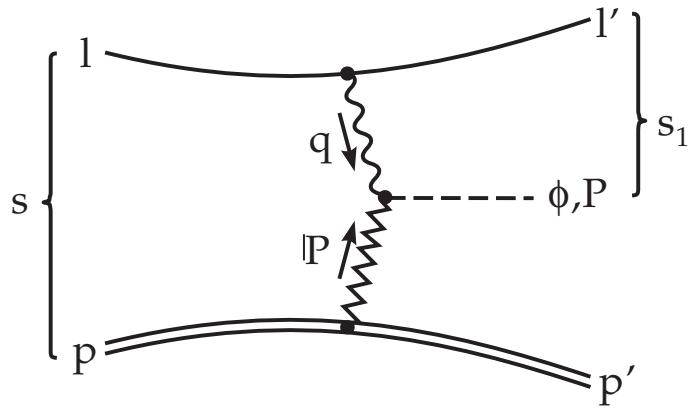


Figure 1: Diffractive Φ production at HERA

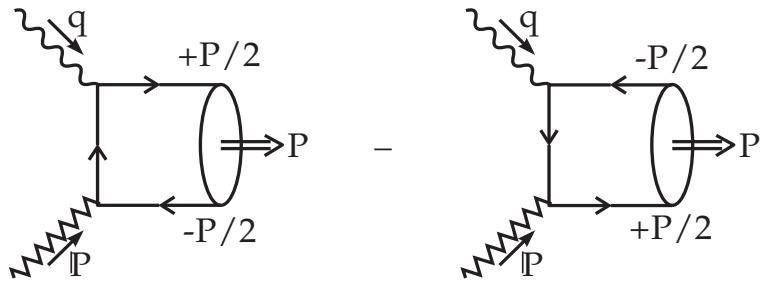


Figure 2: The two contributions to the γ -|P- Φ -vertex

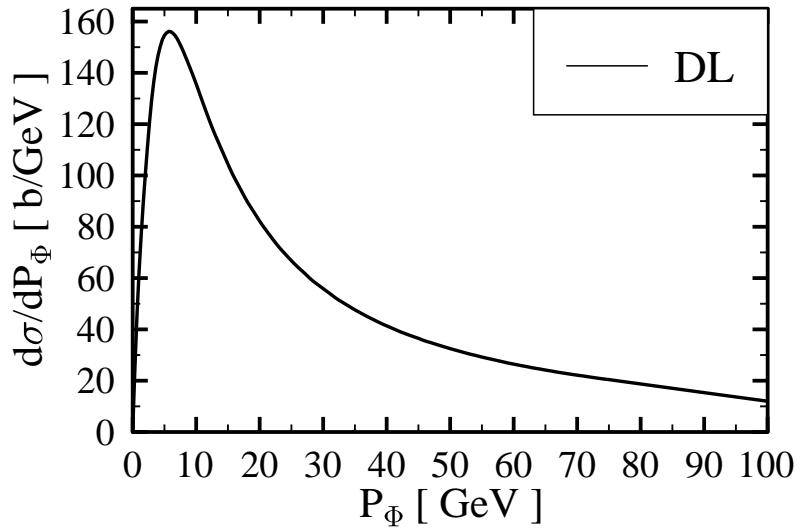


Figure 3: The differential cross section for diffractive Φ production at HERA, calculated with the γ -coupling

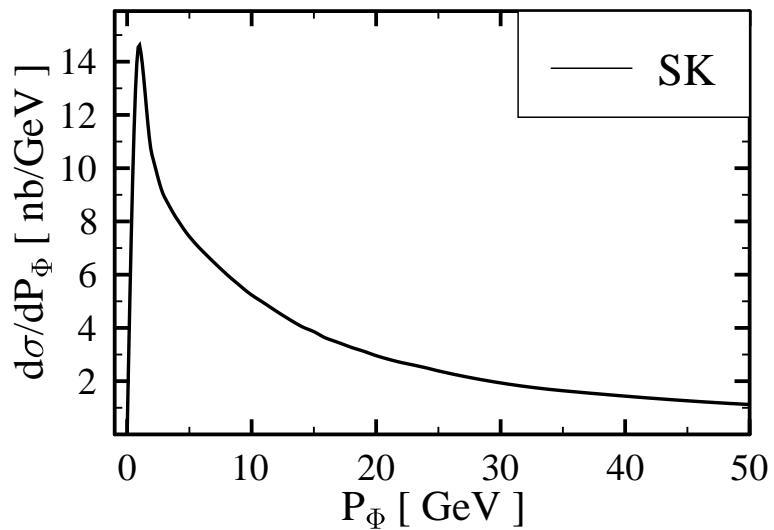


Figure 4: The differential cross section for diffractive Φ production at HERA, calculated with the modified coupling

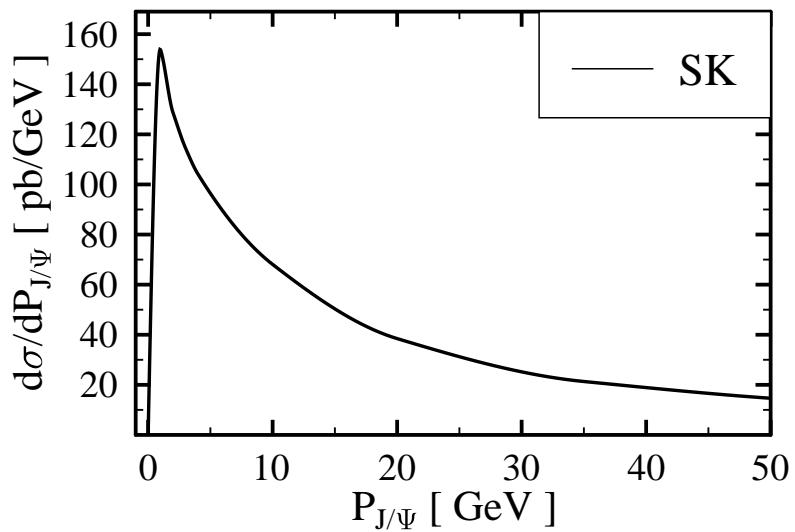


Figure 5: The differential cross section for diffractive J/Ψ production at HERA, calculated with the modified coupling

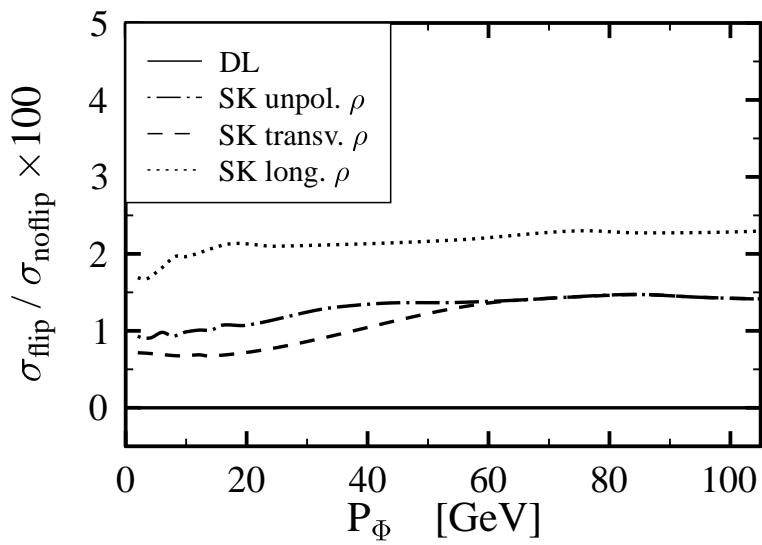


Figure 6: Ratio of σ_{flip} and σ_{noflip} , see text

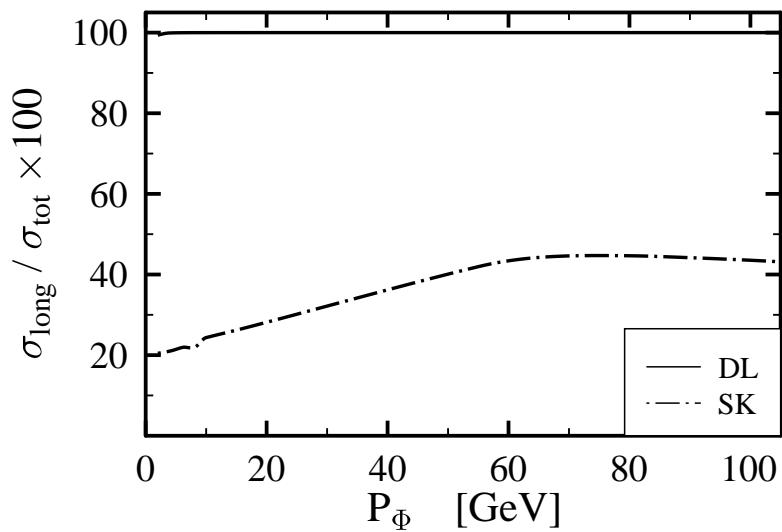


Figure 7: Fraction of longitudinally polarised Φ mesons

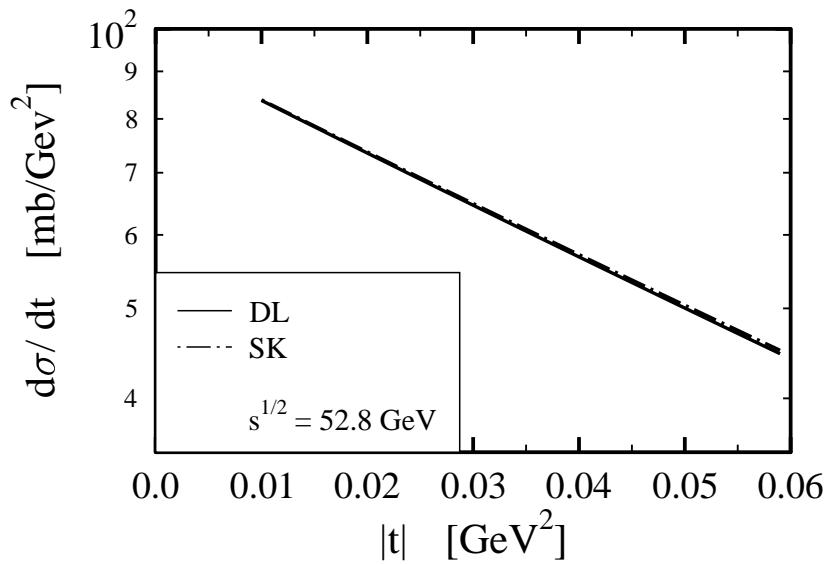


Figure 8: Differential cross section for elastic proton-proton scattering for $\sqrt{s} = 52.8$ GeV

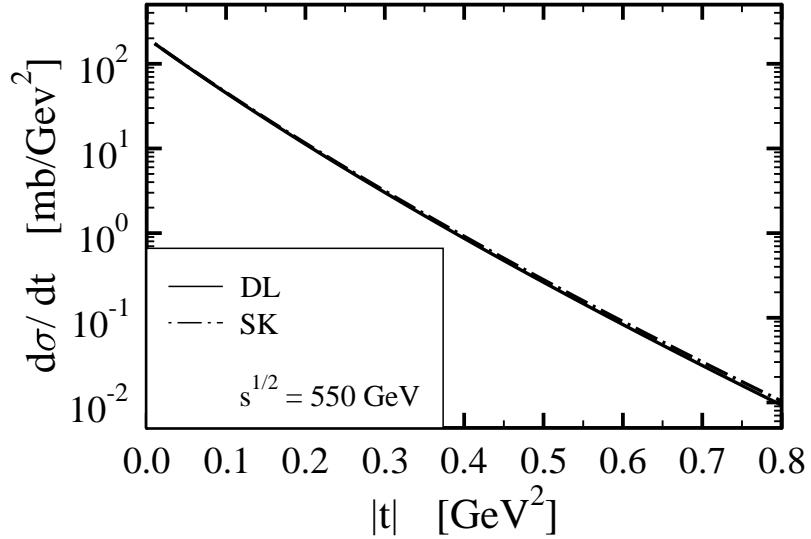


Figure 9: Differential cross section for elastic proton-proton scattering for $\sqrt{s} = 550$ GeV

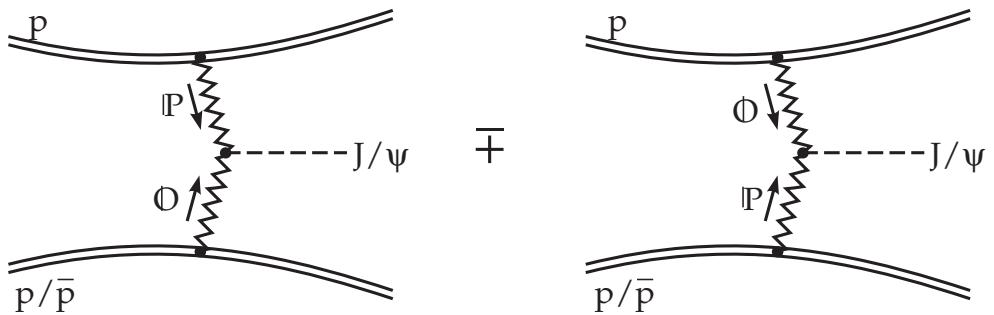


Figure 10: Double diffractive J/Ψ production in NN collisions

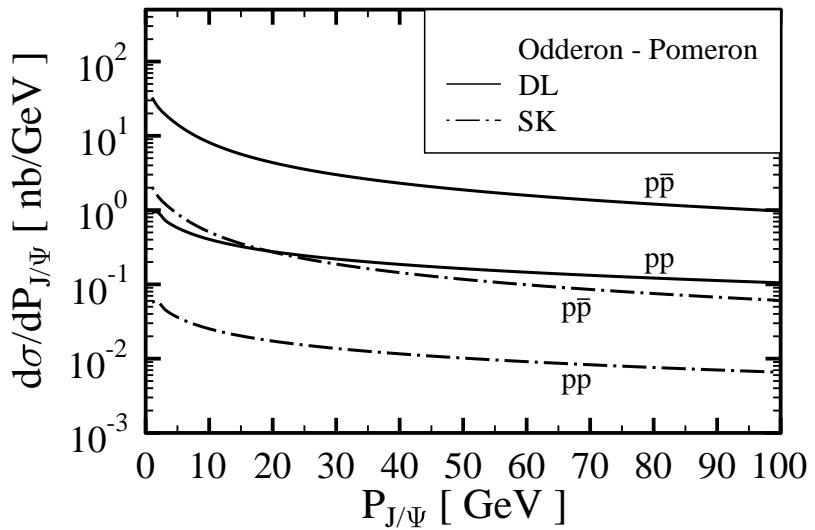


Figure 11: Differential cross sections for double diffractive J/Ψ production at $\sqrt{s} = 2$ TeV

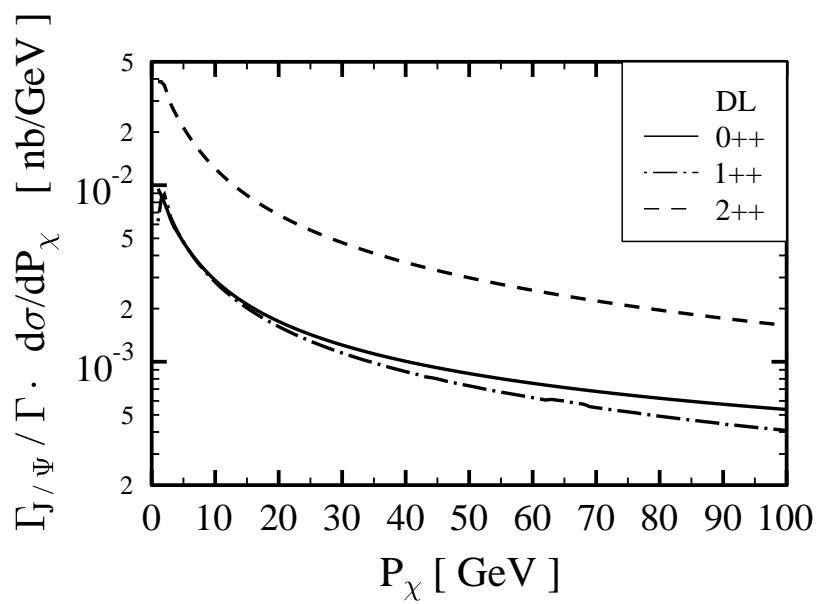


Figure 12: Background of χ mesons obtained with γ -coupling

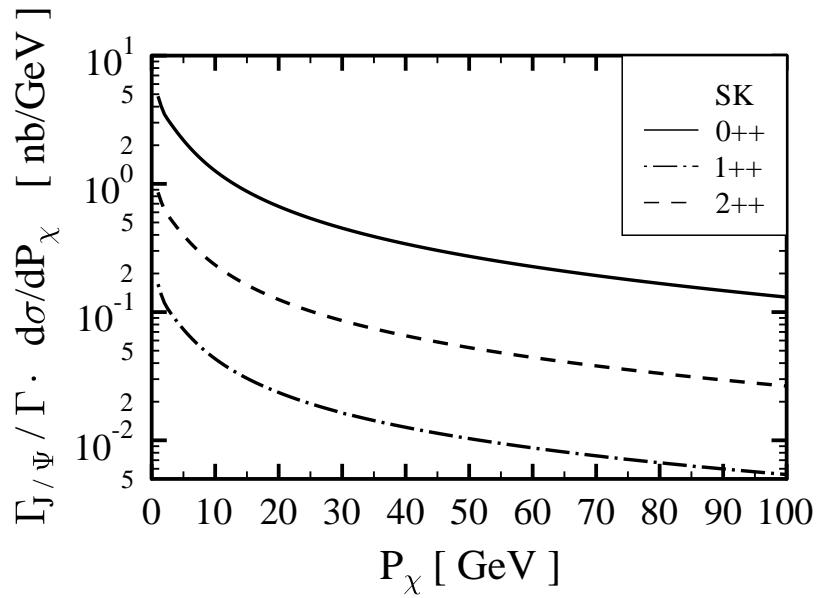


Figure 13: Background of χ mesons obtained with the modified coupling

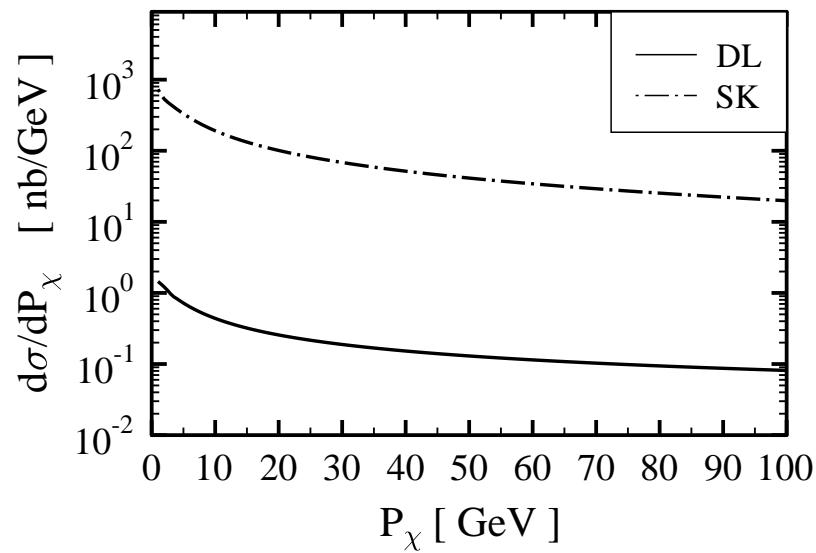


Figure 14: Differential cross section for χ mesons with the different couplings

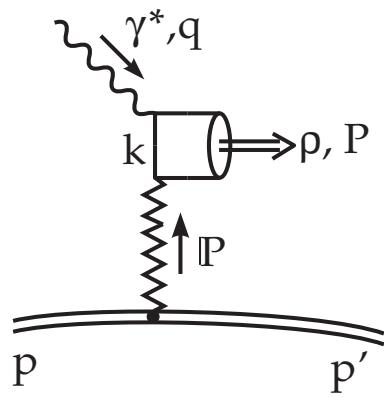


Figure 15: Exclusive ρ production in DIS

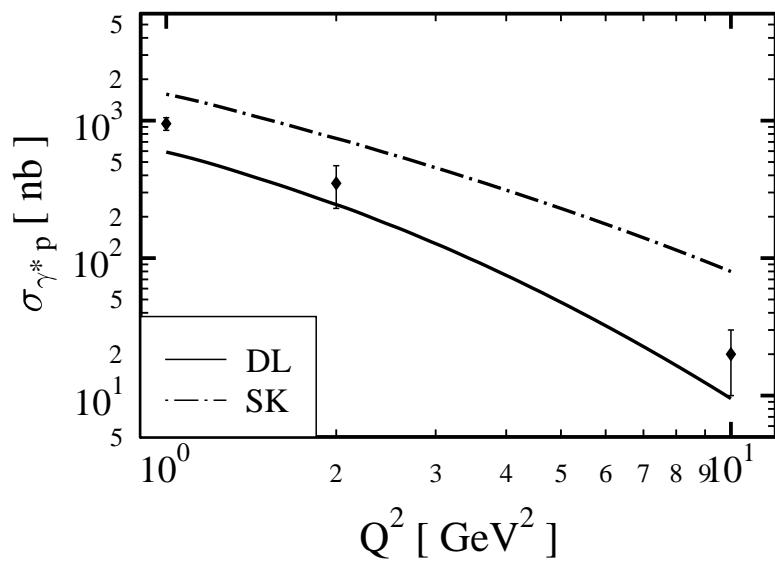


Figure 16: Cross section for exclusive ρ production in DIS

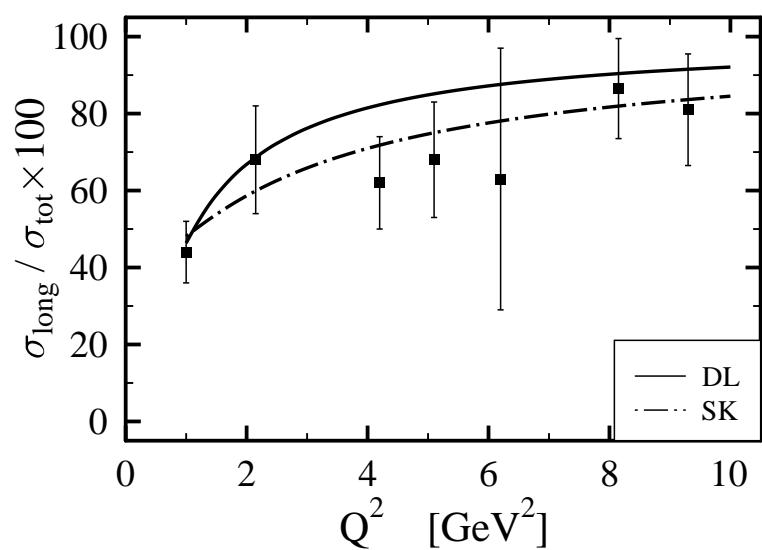


Figure 17: Fraction of longitudinally produced ρ mesons